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13. ABSTRACT (Maximum 200 words)

This report results from a contract tasking Kandilli Observatory and Earthquake Research Institute as follows: The contractor will characterize the seismic structure and behavior of the Anatolian region using data from the Belbasi and Keskin arrays near Ankara, Turkey. The research will include studies to understand the amplitude and phase behavior of seismic signals received at Belbasi and other regional stations operated by KOERI. It will also include studies of the regional seismic velocity structure and tectonic features which affect the signals seen at the array.

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298-102

FINAL REPORT OF

SEISMIC CHARACTERIZATION USING THE BELBASI ARRAY

Submitted by

Kandilli Observatory and Earthquake Research Institute

KOERI

İstanbul, TURKEY

June, 1998

Signature:

Project Director

Prof. Dr. A. Mete Işıkara

DIRECTOR

Signature:

Principal Investigator

Dr. H. Sadi Kuleli

PROJECT SUMMARY

Belbası seismic station (BRSR) has been operated jointly by Turkish General Command and Department of Air Force (AFTAC) of United States of America. Now USA and Turkey are currently negotiating to transfer the operation of array to Boğaziçi University, Kandilli Observatory and Earthquake Research Institution (KOERI). KOERI was designated as the "Turkish Executive Agent" for this turn over. The Belbaşı array is a primary seismic station (array) which will participiate International Monitoring System.

The existing Belbaşı seismic array consists of **6** short period and **1** broadband seismometer. In the near future, the plans call for the relocation of this array to a nearby locality (to KESKİN) and the installation of a new **6** long period and **1** broad band seismometer array to Ankara (Belbaşı). In this project, besides the Belbaşı array, KOERI network (**2** analogue and **5** digital seismic stations on the eastern Turkey) and a IRIS station (ANTO) have been used.

In this report, regional calibration of the station have been studied by using of the seismic P wave velocity distribution. For this purpose, velocity structure and its tectonic implications have been discussed.

In the first report (*progress report, September 1997*) "travel-time information" were used for calculation of the P velocity distribution in the region. In the present (final) report a surface wave and receiver function inversion methods were performed. Both studie are still continuing as to be graduate studies in Boğaziçi University Kandilli Observatory and Earthquake Research Institute. In the appendix of the final report, progress of the Belbası array and all expenditures is included.

1 - PROJECT DESCRIPTION AND OBJECTIVES

The objective of this study is regional calibration of the Belbaşı Seismic Station. For this purpose, seismic structure of the Eastern Anatolia and it's tectonic implications have been studied. In this study besides the Belbaşı seismic array, KOERI and a IRIS station (ANTO) were used. The project were defined with tasks listed below:

Task 1

Seismogram of regional earthquakes and explosions will be constructed as a function of distance at several azimuths from the Belbaşı array and other stations that may be operated by KOERI. An interpretation of these data will be performed that focuses on travel times and amplitudes. Special attention will be given to secondary arrivals. Azimuthal variations in regional wave propagation will be examined, if possible, distinguished from the effects of the seismic source function.

Task 2

Velocity studies will be performed in the region surrounding the Belbası array using receiver function analysis modeling and inversion. Particular attention will be given to an investigation of the effects of source depth on the character of seismic records and any signal characteristics which permit even depth to be determined from visual examination of the waveforms.

Task 3

The technical and logistical support to the construction, maintenance and upgrade of the Belbası, Keskin arrays their telecommunications with KOERI.

The task-1 and task-3 was worked in the "progress Report of this project". The final report of this project is including two new subjects;

1- Surface Wave Inversion with using ANTO station in ANKARAand,

2- Receiver Function Inversion with using Belbaşı array data.

In appendix, the financial framework of this project were implemented.

2 - RESULTS FROM THE FIRST PART OF THIS PROJECT

This results are implemented in the Progress Report (September, 1997)

In this section of the study, velocity distribution of the seismic waves have been calculated for seismic characterization of region. Behalf of the Pn and Pg wave velocities, the Sn and Sg wave velocities were also calculated. In this part of this project seismic velocity were determined from the KOERI stations. The KOERI have 5 digital seismometer installed on the eastern Turkey (Table 1 and Fig. 1). The P and S wave velocities were calculated from conventional travel time-distances method (Table 2) and two station methods (Table 3) on these stations.

A data base have been created consisting of local and regional events after the selection of the arrivals which have a high signal/noise ratio among of collected data. Two different methods have been used for the calculations of velocity values: First, the conventional travel time-distance graphs have been constructed for Pn, Pg, Sn and Sg waves and the velocity values calculated by using lest-square fitting. The velocity values are given at table 2. Second, only Pn velocities between two stations have been calculated by dividing travel time differences to the distances between two stations which are on the same propagation path. The calculated values for Pn wave is given table 3

The average Pn velocity is closely obtained by the first and second methods as the Pn velocity 7.6-7.98 km/s (Table 1, 2) and Pg velocity is ranging between 5.5-6.6 km/s. The average Sn velocity is around 4.3-4.8 km/s and Sg velocity have been changing between 3.3-3.9 km/s. The highest P and S velocity values have been found at the Mediterranean cost of Turkey (Fig. 2).

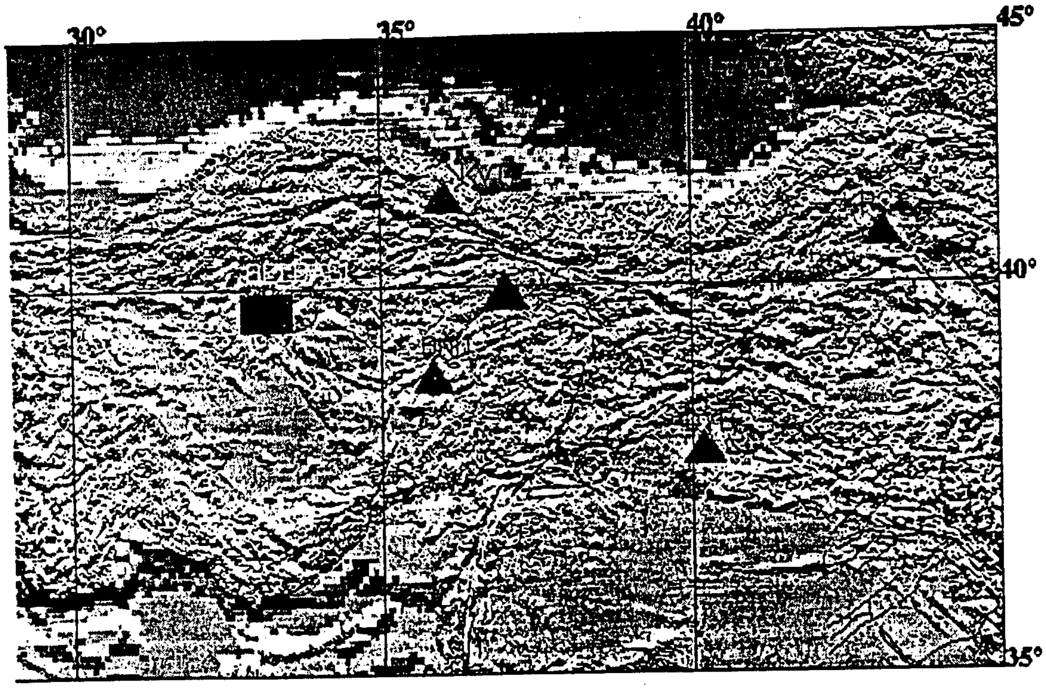


Figure 1

STATION	LATITUDE(N)	LONGITUDE(E)	SENSOR TYPE	SAMPLING RATE (SPS)	COMPONENT
KAVAK (KVT)	41.080	36.047	SS-1	60	VERTICAL
BUNYAN (BNN)	38.852	35.846	SS-1	60	VERTICAL
DIYARBAKIR (DYB)	37.915	40.228	SS-1 and 2 strong motions	60	3(VERTICAL, NS, EW)
KARS (KRS)	40.598	43.110	SS-1 and 2 strong motions	60	3(VERTICAL, NS, EW)
SIVAS (SVS)	39.917	36.998	SS-1	100	VERTICAL

Table 1

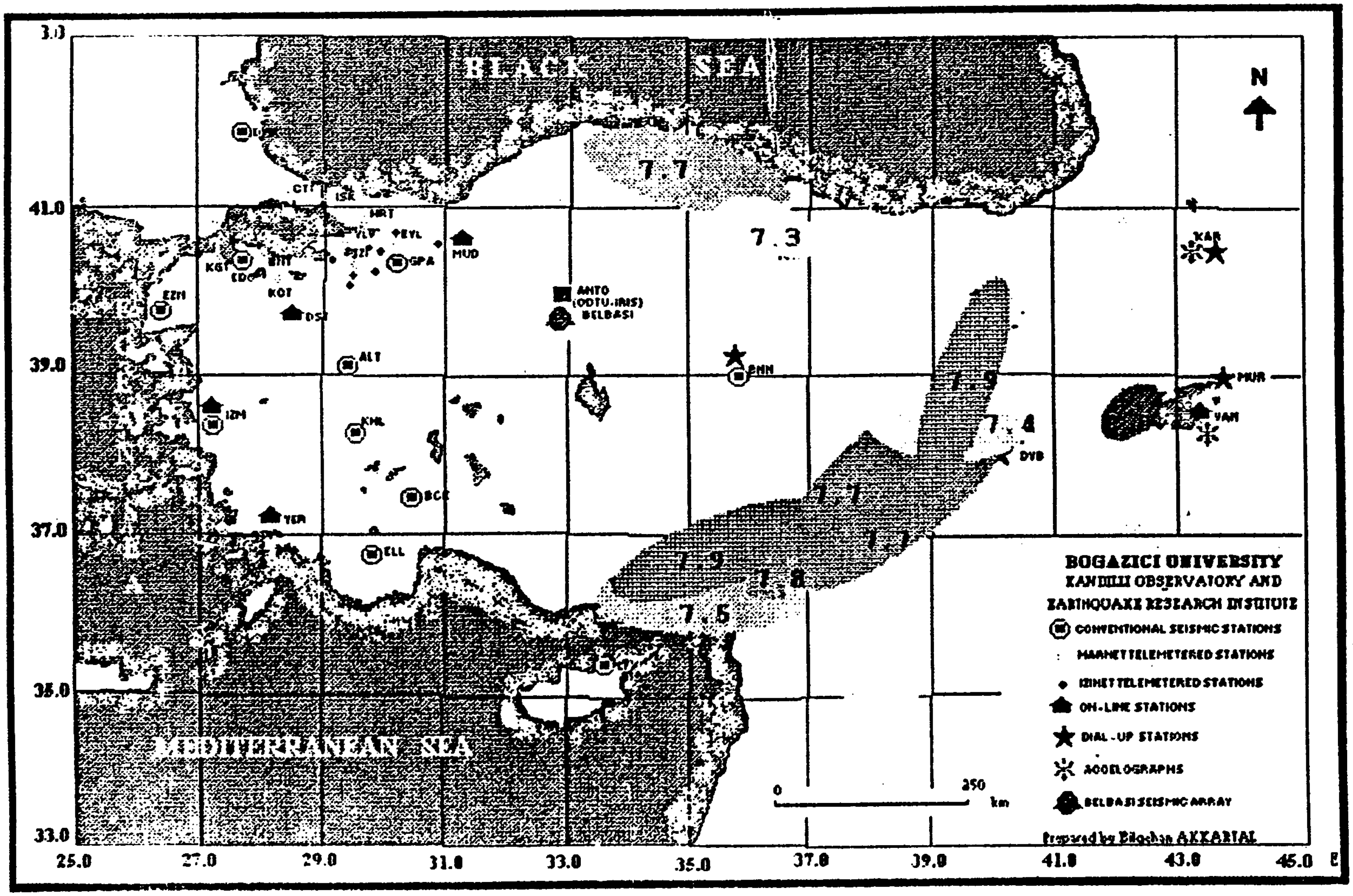
Table 2

Stations	P wave velocity P_n (km/s)	P wave velocity P_g (km/s)	S wave velocity S_n (km/s)	S wave velocity S_g (km/s)
ERZ	7.62	5.70		4.00
DYB	7.70	6.34		3.76
MYA	7.90	6.00		4.21
BNN	7.56	5.47	4.38	3.34
GAZ	7.86	5.78	4.60	3.86
IKL	7.98	6.63	5.75	4.57
HTY	7.78	5.85	5.00	4.26

Table 3

Stations	Velocity (km/s)	Average
GAZ-HTY	7.9	
	7.9	
	7.7	
	8.0	
	7.5	
	8.1	
HTY-GAZ	7.9	
	7.9	
	7.9	
		7.86
MYA-GAZ	7.8	
	7.8	
	7.6	
	7.5	
	7.4	
	7.9	
	7.8	
	7.8	
GAZ-MYA	7.7	
	8.2	
	7.7	
		7.74
IKL-HTY	6.6	
	7.9	
HTY-IKL	7.5	
	7.5	
		7.4~7.5
DYB-GAZ	7.8	
	7.7	
		7.75

KVT-BZK	7.5	
	7.5	
	8.2	
		7.7
TOK-KVT	7.2	
	6.8	
	7.3	
		7.1~7.3
DYB-MYA	7.4	7.4
ERZ-MYA	7.9	
MYA-ERZ	8.1	
		8.0
BTL-ADL	8.4	8.4



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DVB
BNN
BOGAZICI UNIVERSITY
KANDILLI OBSERVATORY AND
EARTHQUAKE RESEARCH INSTITUTE
CONVENTIONAL SEISMIC STATIONS
MARMARA TELEMETERED STATIONS
IZNIK TELEMETERED STATIONS
ON-LINE STATIONS
DIAL-UP STATIONS
ACCELOGRAPHS
BELBASI SEISMIC ARRAY
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Figure 2

3 - SEISMIC SURFACE WAVE INVERSION

In the present study seismic surface waves are used to investigate the shear-velocity structure of the crust beneath the central and western Turkey. Data obtained from the ANTO station. This station is located closely to Belbaşı array. This is a single three-component broadband (Teledyne-Geotech Model 36000) which was installed in a 7-inch borehole.

ANTO, IRIS STATION IN ANKARA

Code	lat, long	Elev.(m)	Depth (m)	Geologic Foundation
ANTO	39.8689N; 32.7936E	883	195	Hard Rock

Recent improvements in methods for determining surface wave group velocities (Russell, Hermann and Hwang 1984) and in the inversion of those data (Russell 1987; Hwang and Mitchell 1987) should allow us to place greater constrains on crustal velocities, as well as on crustal thickness.

Four volumes of computer programs which were written by Robert B. Hermann are used to invert surface wave data to get depth distribution using group velocities. These programs were developed from 1970 to 1985 by R. B. Hermann, C. Y. Wang and D. Russell which introduced below in brief.

Volume 1 Just includes programs to support graphics

Volume 2 provides a set of programs to perform some routine seismological functions, such as calculating distances on an ellipsoidal earth as well as a general purpose spectral analysis package composed of simple modules.

Volume 3 describes a series of programs that compute the surface waves in plane layered elastic medium due to a point source. The medium consist of homogeneous plane layers overlying an elastic halfspace. The source as well as the receiver can be located at any distance in the medium.

Volume 4 provides a complete package for the inversion of surface wave data for earth structure, as well as other programs for use with surface wave data. Surf(4) is an interactive program for inverting Love or Rayleigh, phase velocity, group velocity and gamma values for an earth structure. For this study, earthquakes have been selected from the Aegean region and magnitudes 5 or bigger for inversion process (Fig. 3).

Earthquakes have been selected for inversion Process

Date	Time	Coordinates	Depth (m)	Magnitude
15 May 1979 ED3	11:44:45.9	38.81N 26.53E	23 km	5.8
18 March 1993 EQ1	15:47:00.4	38.3N 22.2E	59 km	5.8

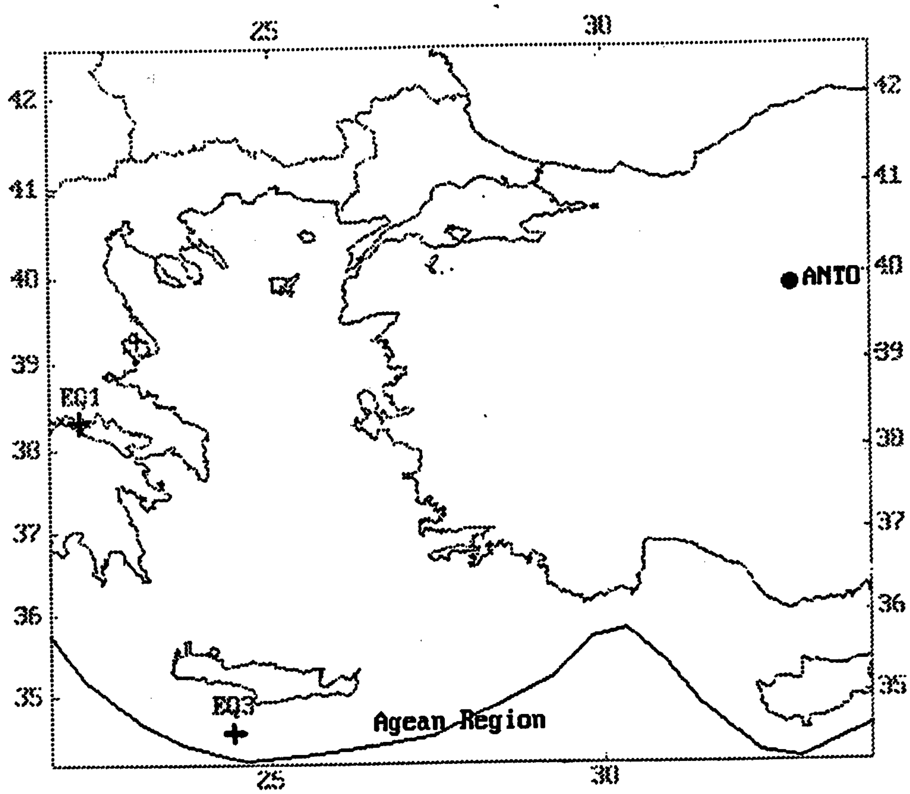

Figure 3

Two Earthquakes (EQ1 and EQ2) were used for surface wave inversion.

For both earthquakes long period records of N, E and Z components were downloaded. In these components, N and E are used for group velocities for love wave and Z component is used to calculate group velocities for Rayleigh wave. Two different types of inversion used: The first is stochastic (no smoothing), the second is differential inversion. For both types non-causal inversion preferred. Spectral amplitudes and group velocities have been given for Love and Rayleigh waves (Fig 4). Initial earth model has been selected according

to our previous studies.

Initial earth model

Layer thickness	P velocity	S velocity	Density	Q_b^{-1}
0	1	2.25	1	1
5	4.5	2.78	2	0.02
13	5.8	3.58	2.5	0.01
15	6.1	3.77	2.8	0.005
0	7.85	4.85	3.3	0.002

The inversion result is given Fig. 5. According of these inversion result, average crustal depth is calculated about 30 - 35 km. This output seems reasonable for western Turkey. But seismic shear velocity especially below the crust calculated lower than expected value.

This surface wave inversion study is still continue as to be a graduate project. The method will applied to Belbaşı data.

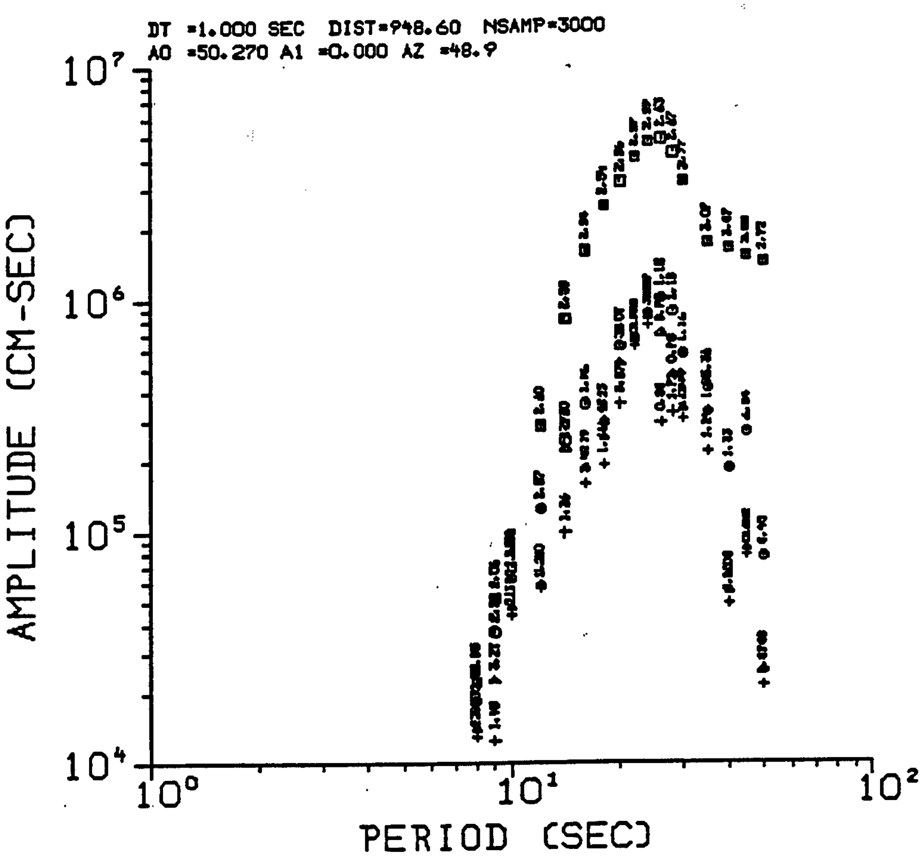

Figure 4

Spectral amplitude versus period for Rayleigh waves earthquake, 1979 May 15, 06:59:21.2

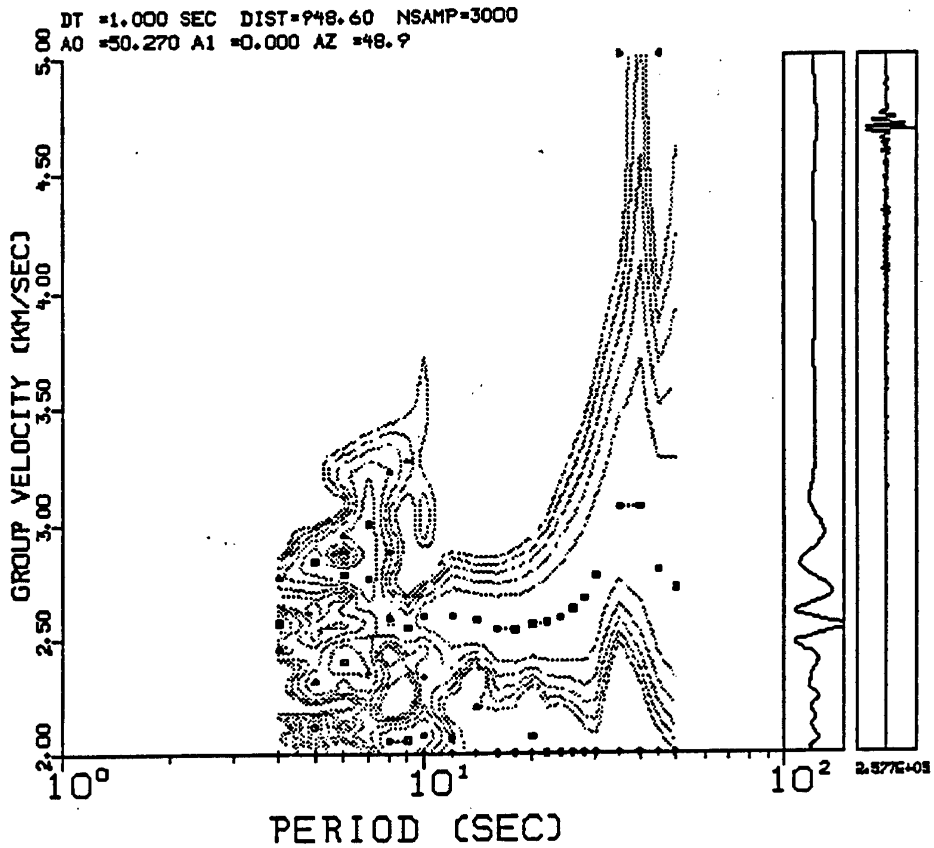

Figure 4

Group velocity for each peak versus period for Rayleigh waves of earthquake, 1979 May 15, 06:59:21.2

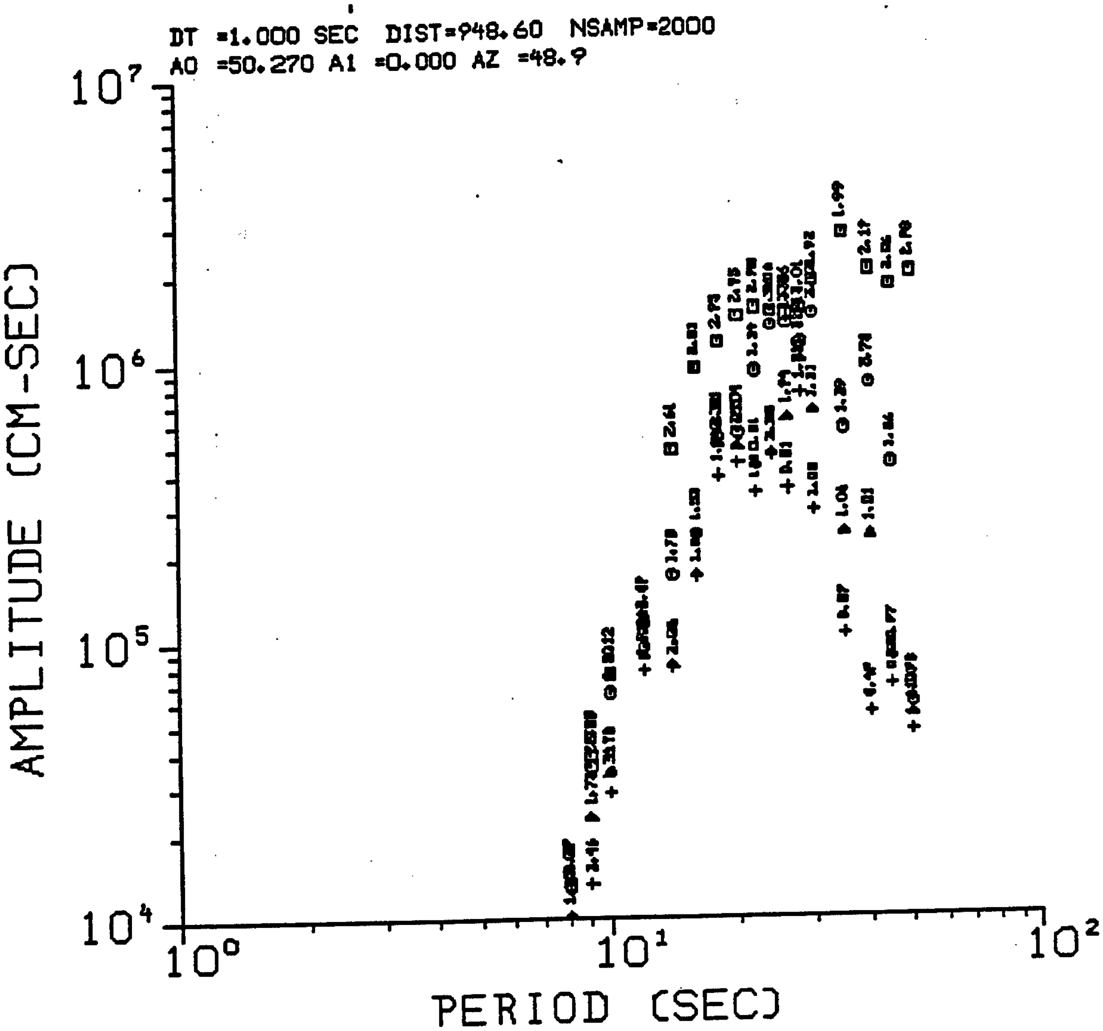

Figure 4

Spectral amplitude versus period for Love waves earthquake, 1979 May 15, 06:59:21.2

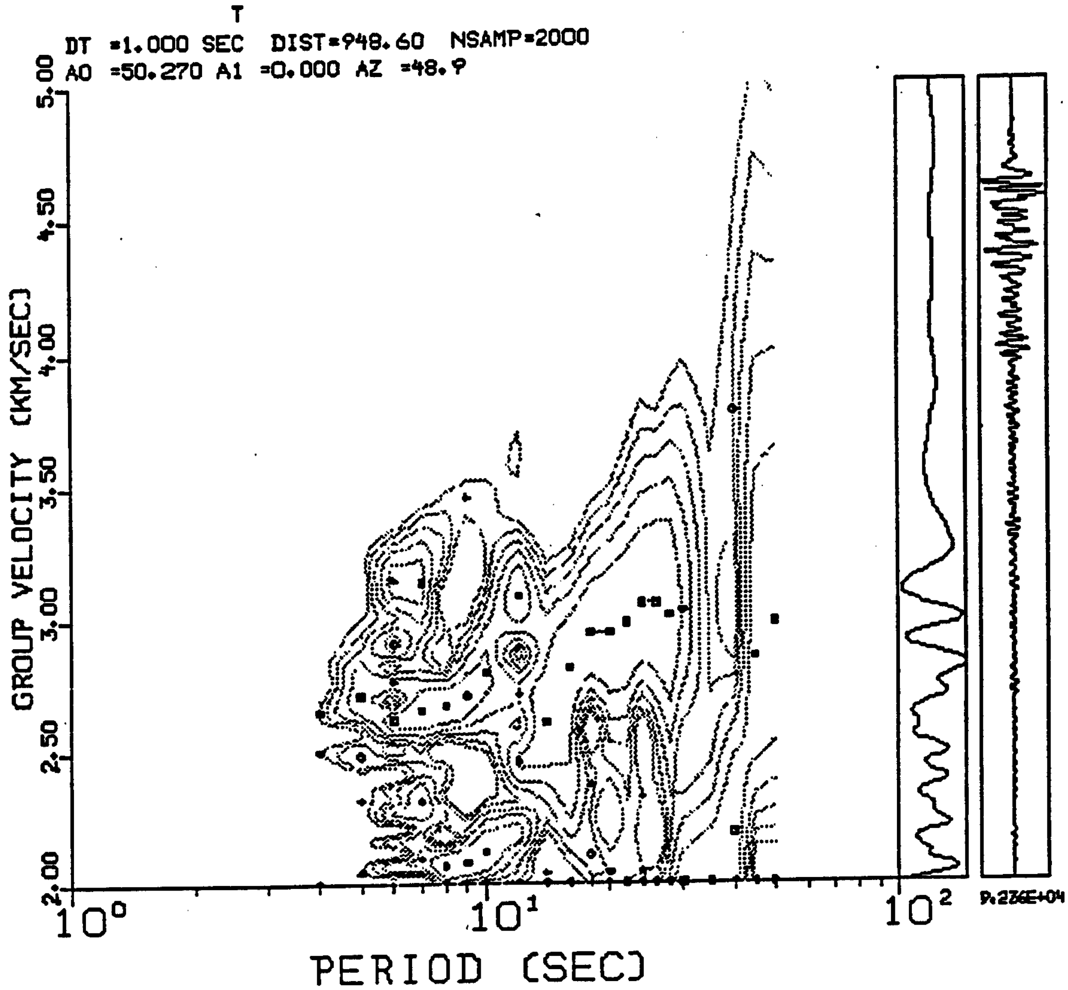

Figure 4

Group velocity for each peak versus period for love waves of the aerthquake, 1979 May 15, 06:59:21.2

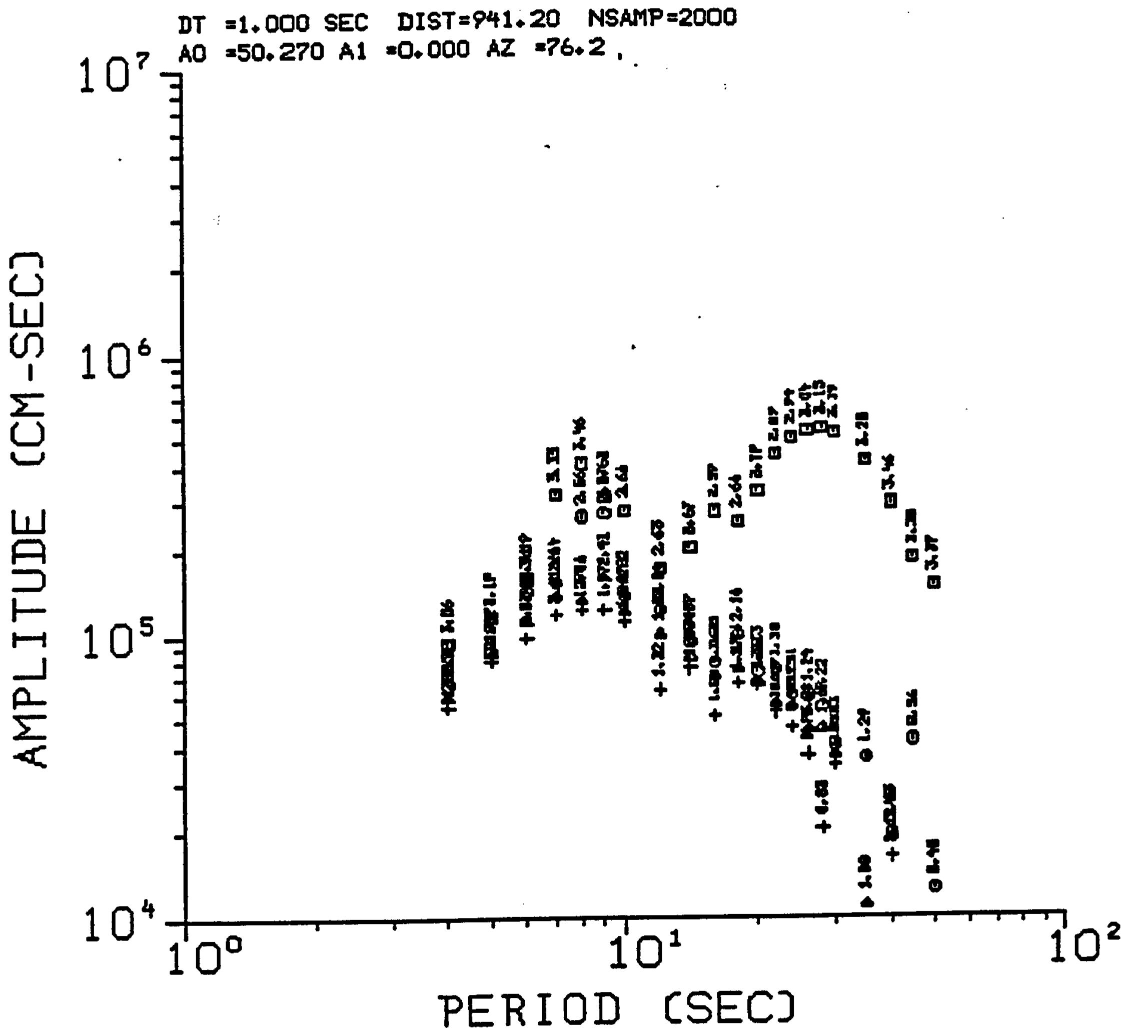

Figure 4

Spectral amplitude versus period graphic for Rayleigh waves earthquake, 1993 March 18, 15:47:0.4

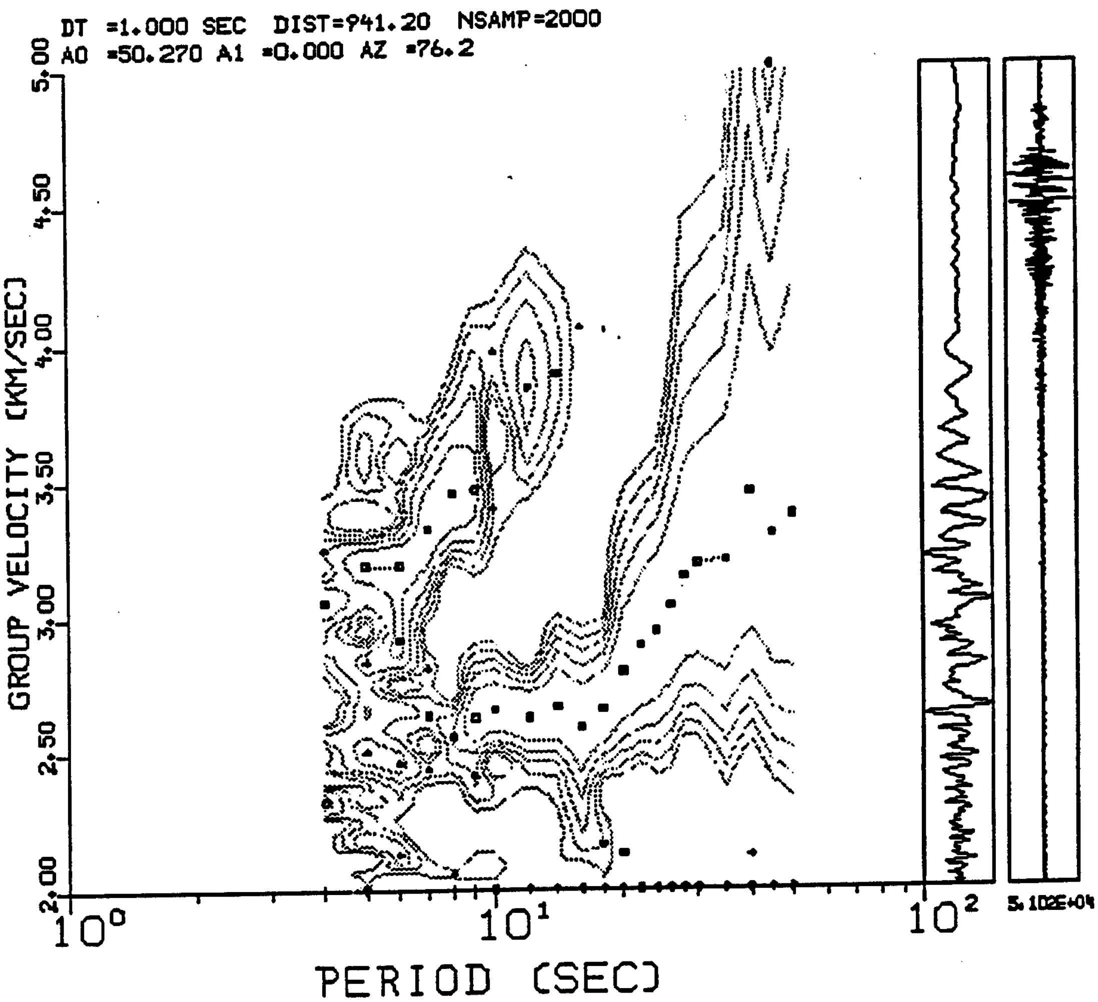

Figure 4

Group velocity for each peak versus period graphic for Rayleigh waves of earthquake, 1993 March 18, 15:47:0.4

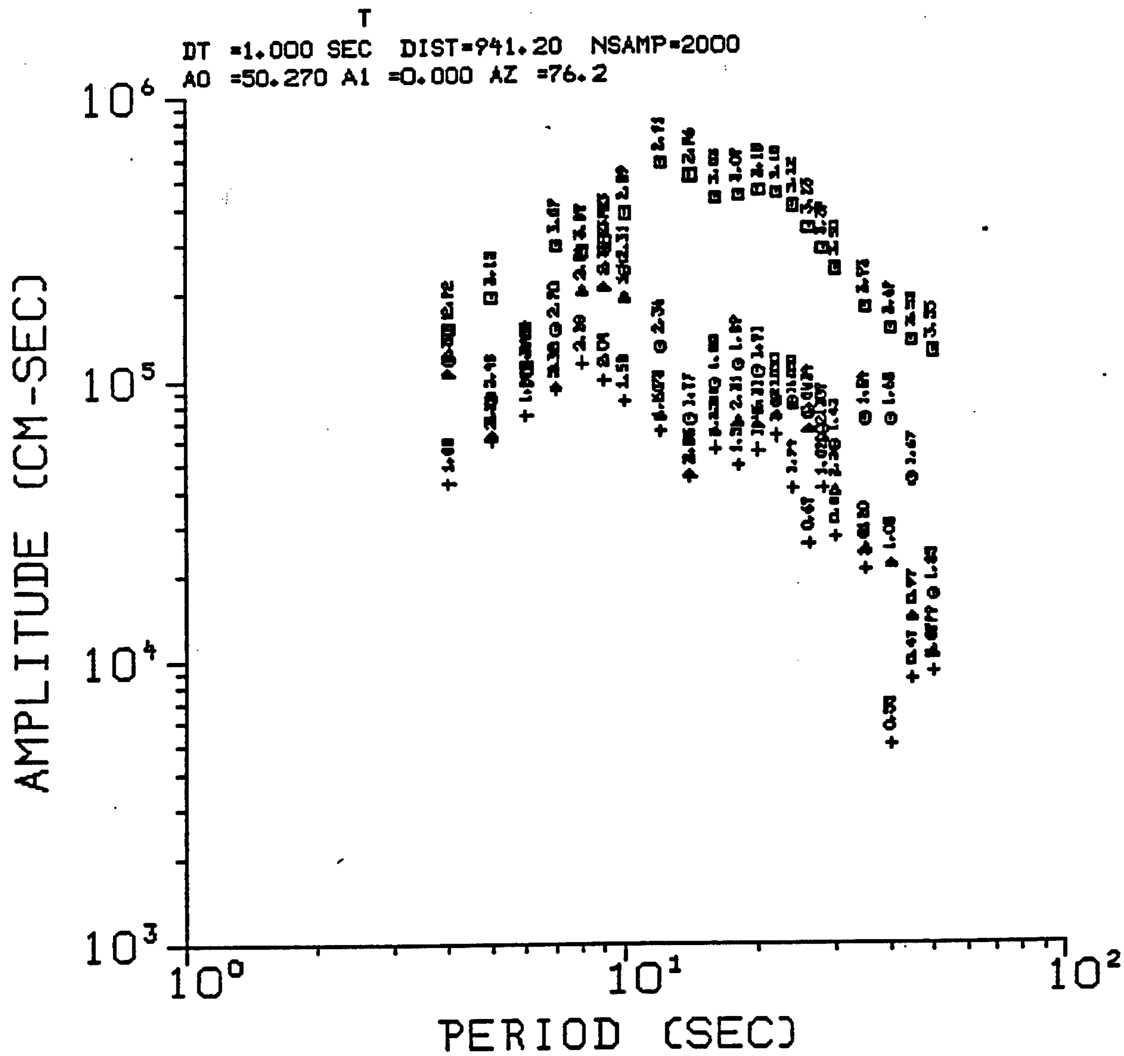

Figure 4

Spectral amplitude versus period graphic for Love waves earthquake, 1993 March 18, 15:47:0.4

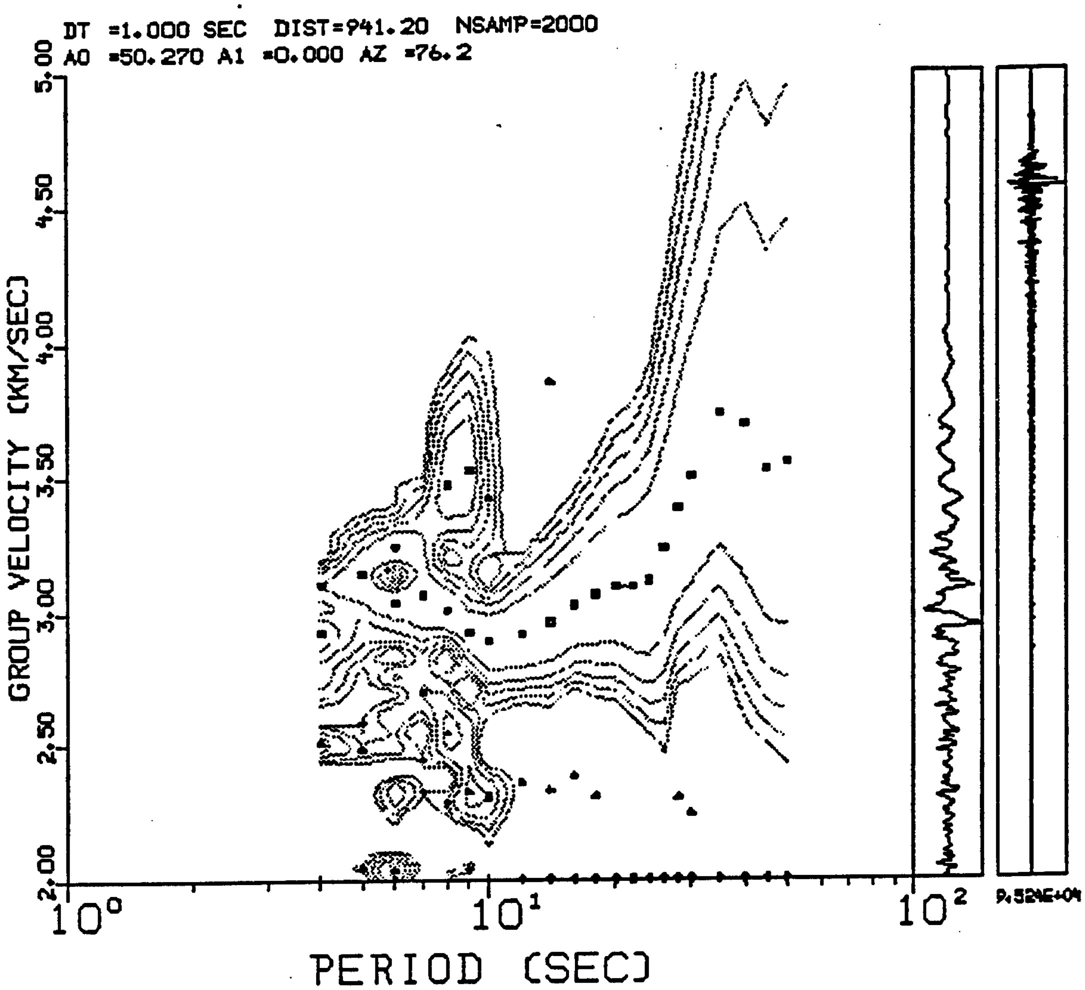

Figure 4

Group velocity for each peak versus period graphic for love waves of the aerthquake, 1993 March 18, 15:47:0.4

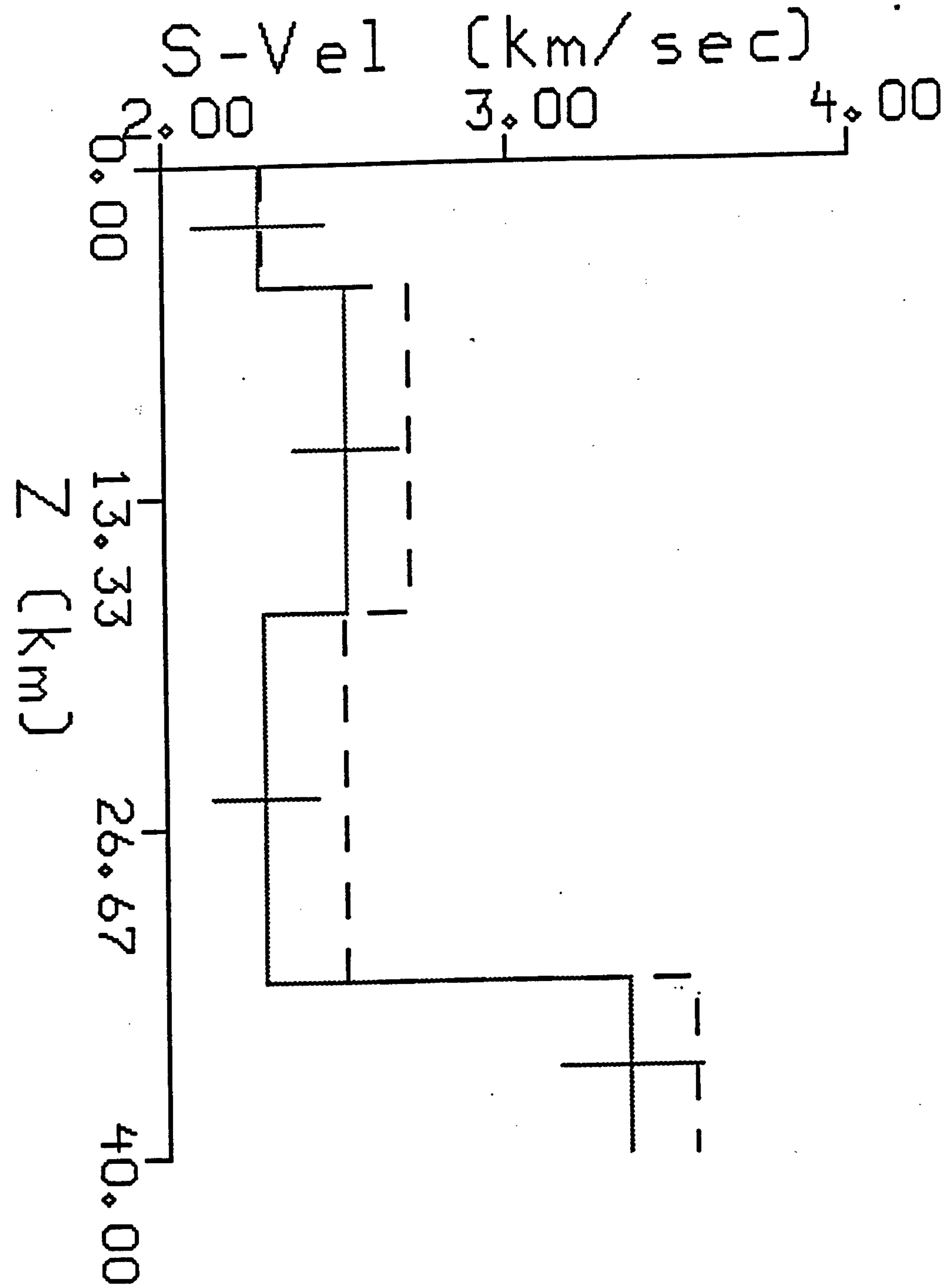

Figure 5

The result of S velocity and depth inversion by differantial inversion method.

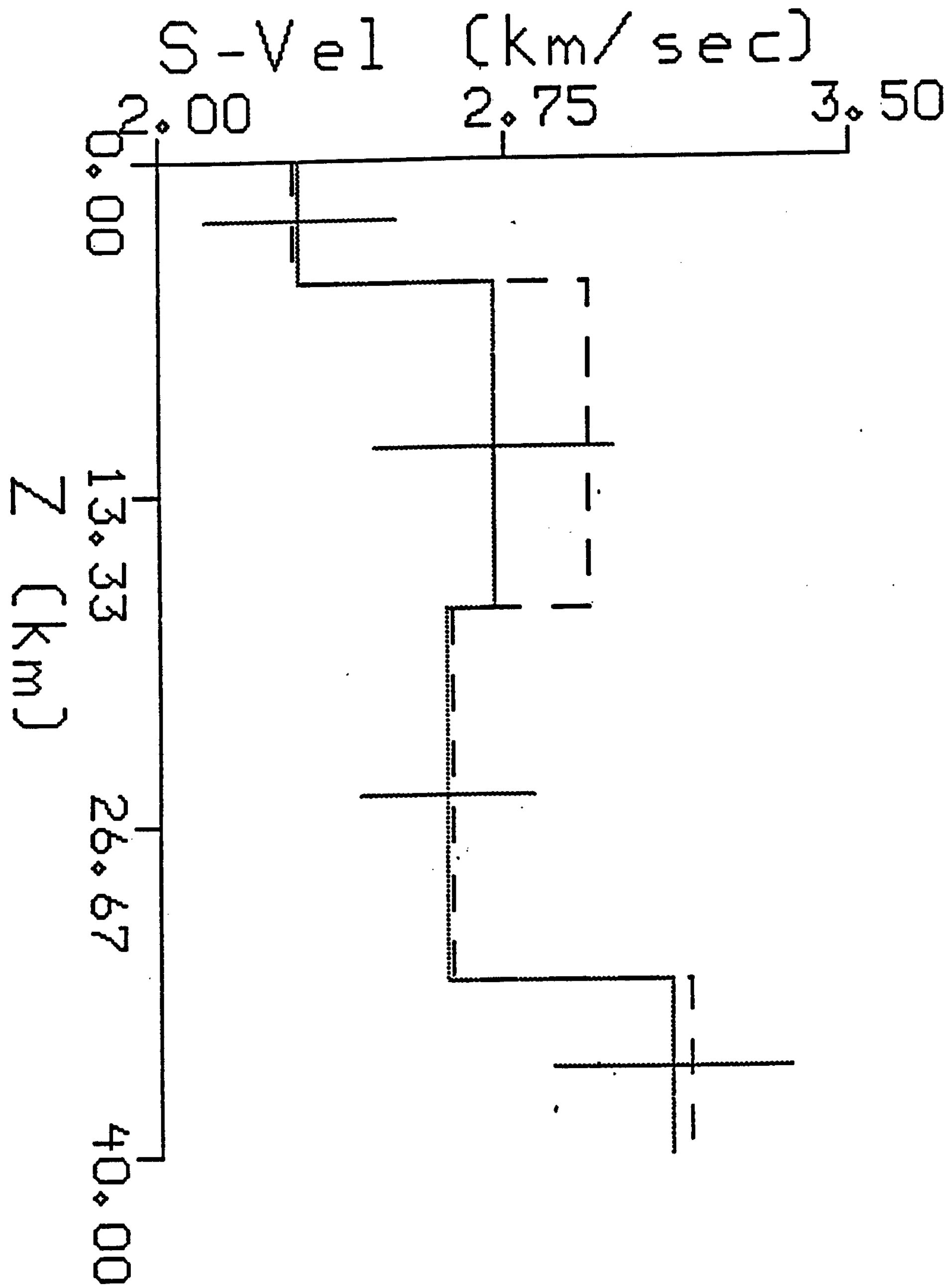

Figure 5

The result of S velocity and depth inversion by stochastic inversion method.

4 - RECEIVER FUNCTION INVERSION

BELBASI ARRAY:

Belbası Seismic Station has been operated jointly by Turkish General Command and AFTAC. Now USA and Turkey are currently negotiating to transfer the operation of array to a civilian body and we have (Boğaziçi University, Kandilli Observatory and Earthquake Research Institution: KOERI) been designated as the "Turkish Executive Agent" for this turn over.

At this moment, Belbası seismic array consists of **6** short period and **1** broad band seismometer. The seismometers are located around of the Ankara and the operation center of the existing array is located at Belbası. Belbası is a town of Ankara city. The existing array have been operated by the Air Force Technical Application Center (AFTAC) and Turkish General Staff (TGS). The coordinates and graphical representation of existing array are given below (Fig. 6).

In the near future, the plans call for the relocation of this array to a nearby locality (to KESKİN) and the installation of a new **6** long period and **1** broad band seismometer array to Ankara (Belbaşı). The both array will be operated for IDC (International Data Center). The data will transfer to directly to IDC (Vienna), AFTAC and the Istanbul campus of KOERI.

In this section receiver function inversion was performed for calculation of the velocity structure beneath the Belbaşı station. The teleseismic three component waveforms have been used to for this method.

The receiver function based on a technique proposed by Langston (1979) consisting of simple deconvolution of vertical component from the radial and transversal components. In this process the eliminate the near-source, mantle-path and instrument response effects leaving a signal composed of primarily S wave conversions and reverberations below the stations. Deconvolution can be performed also in the frequency domain (Owens et al., 1984) as well as time domain. The frequency domain deconvolution uses a Gaussian filter and spectral filter to stabilize the receiver functions.

A gaussian filter value with of 1.5 and trough 0.001 were then tested to produce smooth and stable deconvolutions. A low pass filter 0.8 Hz was applied to three component teleseismic recordings within a time window of 20 sec that is being 5 sec before the direct P arrival. The N-S and E-W components were then rotated to the radial and transversal directions to obtain the vertical polarized SV components and the transversal directions to obtain the vertically polarized SV components and the transversally polarized SH com-

ponents respectively. In order to get true radial and transversalreceiver functions, the wavefild polarization technique was used to correct backazimuth.

The resulting individual receiver functions were shown on Fig. 8 a,b for 3 Component station in Belbası Array. First and second bars indicate P_s and PP_mS picks respectively. The receiver functions were sorted withrespect to epicentral distances.

The Ps converted phase were picked according to highest amplitude in secondary arrivals. Assuming a homogeneous and isotropic crust with poison ratio of 0.25 and average crustal P wave velocity of 6.2 km/s. have been selected. The equations that is used for moho depth calculations were calculated by using

$$h = \frac{T_{ps}V_p}{1.73Cos(\phi_s) - Cos(\phi_p)}$$

Where V_p is the average crustal P wave velocity, T_{ps} is the difference between t_p and t_s that are the arrival time for direct P phase and moho P_s converted phase respectively, p is the ray parameter, ϕ_s and ϕ_p are the angle of incidence for Ps times for individual receiver functions, and crustal thickness variations are obtained. When the average crustal velocity accepted as 6.2 km/s average crustal thickness was calculated as 34.119 $\pm$1.80.

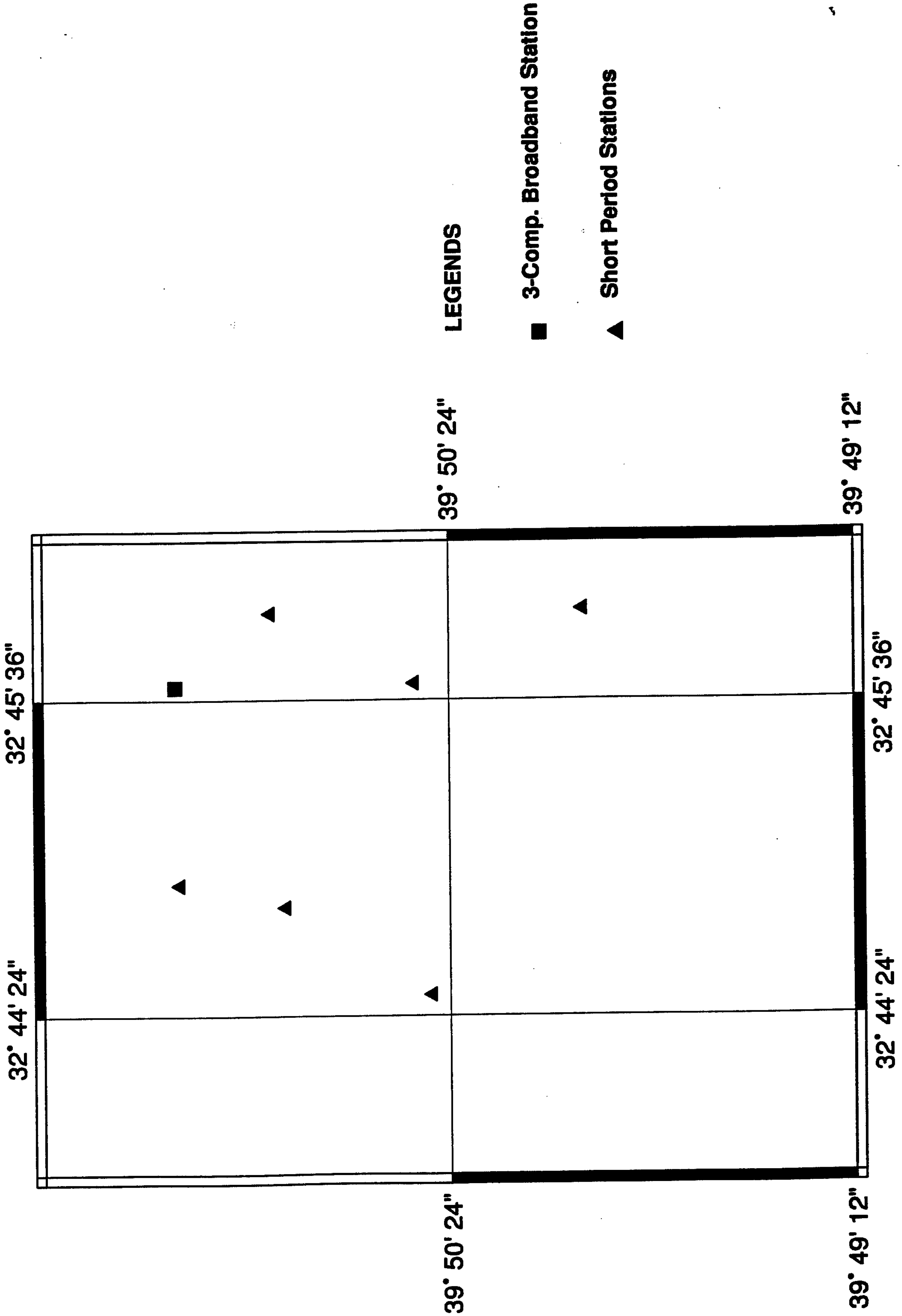
LEGENDS
3-Comp. Broadband Station
Short Period Stations
39° 50' 24"
39° 49' 12"
32° 45' 36"
32° 44' 24"
32° 45' 36"
32° 44' 24"
39° 50' 24"
39° 49' 12"

Figure 6

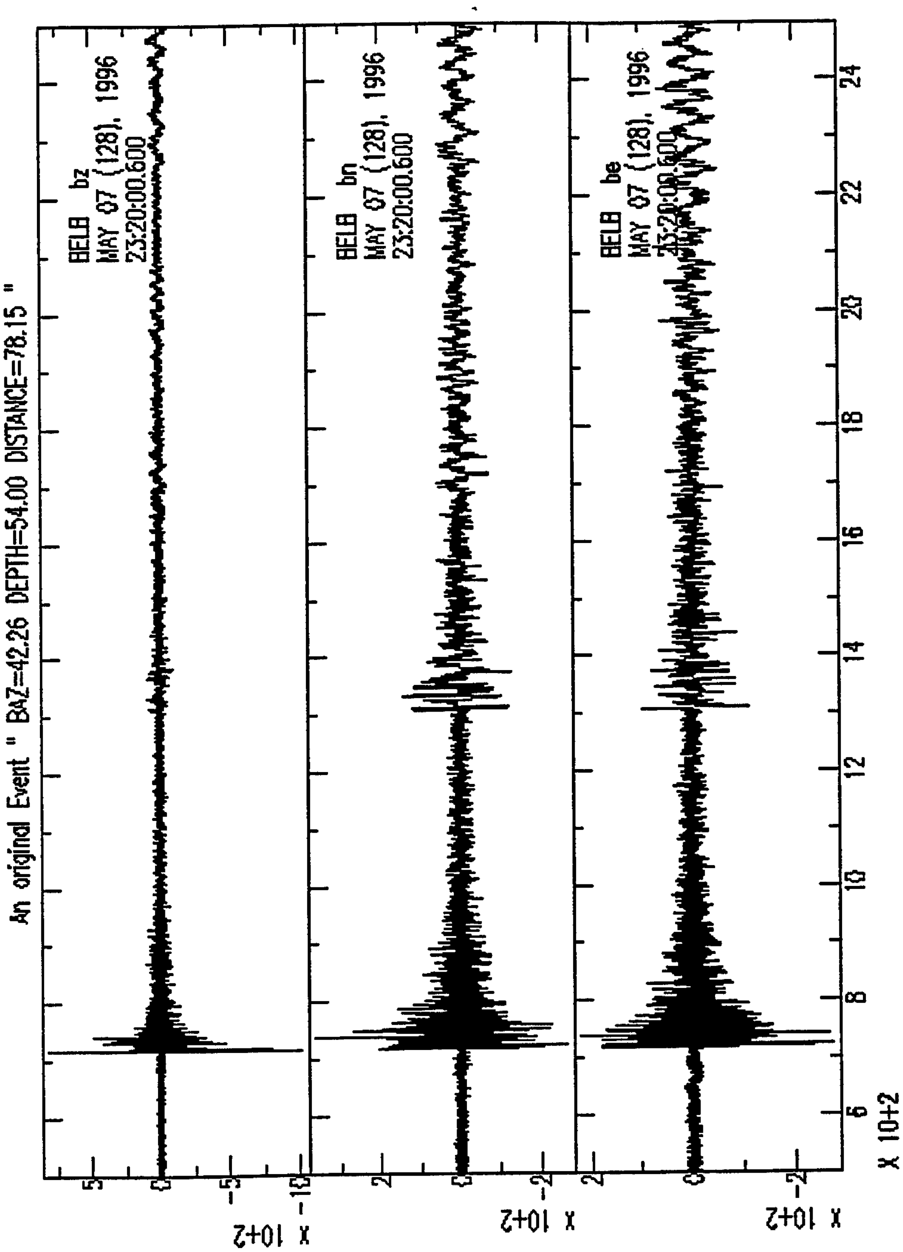

Figure 7

A waveforms of Belbaşı 3-Component Broadband station.

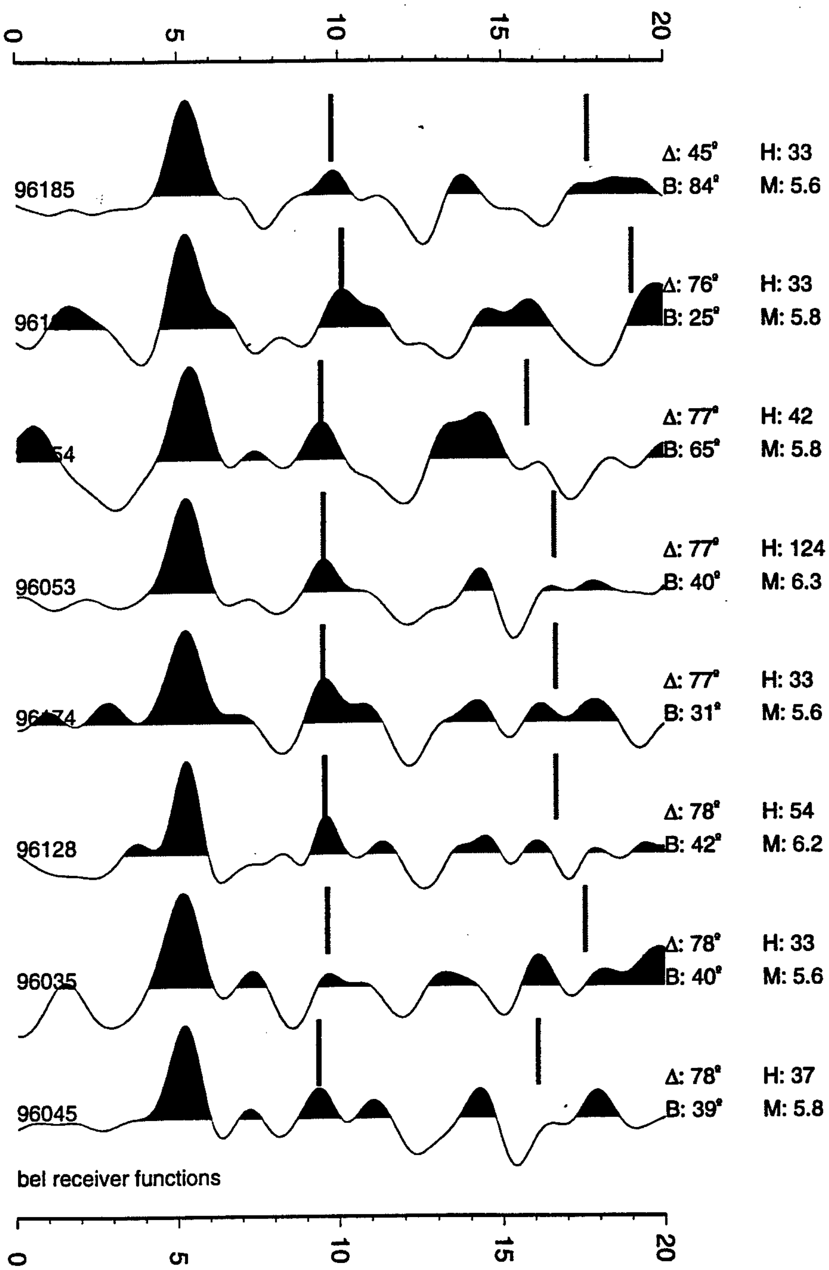

Figure 8 a

The receiver functions of selected event in 1996.

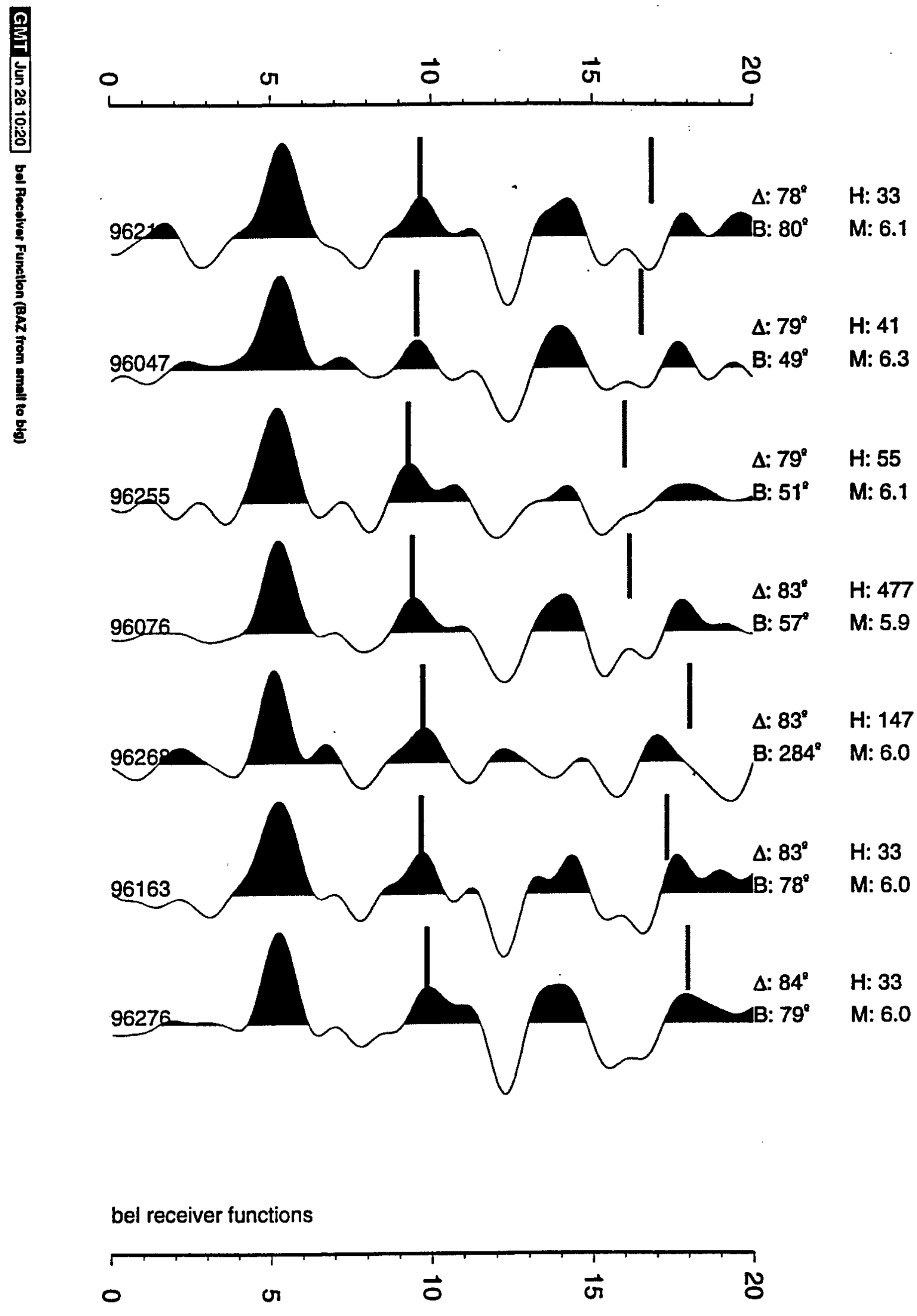

Figure 8 b

The receiver functions of selected event in 1996.

CONCLUSION

In this project, "seismic characterization" concept has been used to imply "regional station calibration". For this purpose, seismic velocity distribution were calculated in the Anatolia. The project implemented in two section.

In the first section (see *progress report, 1997*), seismic velocities were calculated from the travel-times of the seismic waves arrivals. The travel times were calculated for the KOERI stations. The average Pn velocity is obtained as 7.6-7.98 km/s (Table 1, 2) and Pg velocity is ranging between 5.5-6.6 km/s. The average Sn velocity is around 4.3-4.8 km/s and Sg velocity have been changing between 3.3-3.9 km/s. The highest P and S velocity values have been found at the Mediterranean cost of Turkey. The average Pn velocity for entire east Anatolia is lower than the world-wide average continental upper-mantle Pn velocity of 8.1 km/s (Mooney and Braile). This result is consistent with Chen and Molnar, (1980) who calculated seismic velocity for upper-most mantle as 7.73±0.08.

In the present stage of the project, we concentrated mostly inversion of the seismic signal for velocity distribution. Since recently access of the Belbaşı data, only receiver function inversion have been applied to this data. Besides the receiver function inversion surface wave inversion method have been applied to long period data form Anto (IRIS) station. The preliminary studies of inversion methods indicate that crustal thickness is about 34 km in central Anatolia. The shear velocity values is not obtained meaningful from the surface wave inversion. The both inversion project are still continue as to be graduate studies.

APPENDIX

PROGRESS ON THE LOGISTICAL SIDE

KESKİN

1- **Construction of the array is finished.**

2- **Construction of office buildings:**
Construction company is planning to finish the main construction the end of this year. We are sending photos from the construction of Belbaşı station.

3- **Tower and LP A :**
The process of the installation of the telecommunation tower near the new site of office building is going on.

4 - **JOWS (GOVERNMENT FURNISHED EQUIPMENT):**
The all equipment arrived to KOERI and installed.

EXPENDITURES

From the first period of this study (October 1996-October 1997), financial framework had been given by Progres Report. In the second period of the project a similar financial plan will be accepted.

• a. Labor:	$ 6.000
• b. Maintenance of GFE (computer hardware):	$ 3.000
• c. Materials:	$ 1.000
• d. Communication Link:	$ 5.000
• e. Travel:	$ 5.000
TOTAL (Items a-e):	$ 20.000

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TOTAL (Items a-e):	$ 20.000

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20/01/98			NAKiT	20/01/98	2199$ A.METE IŞIKARA		471,910,112			2,445,224,382
21/01/98			NAKiT	21/01/98	2976$ MERIDYEN TICAR		638,250,000			1,806,974,382
26/01/98			NAKiT	26/01/98	3558$ AGMA INŞAAT		759,000,000			1,047,974,382
28/01/98			NAKiT	28/01/98	2416$ ASM INŞAAT		517,500,000			530,474,382
30/01/98			NAKiT	30/01/98	1017$ P.YALINGÜN GID		214,145,000			316,329,382
02/02/98			NAKiT	02/02/98	170$ P.YALINGÜN GID.		35,850,000			280,479,382
27/02/98			NAKiT	27/02/98	1000$ S.KULELI GIDER		221,000,000			59,479,382
03/04/98			NAKiT	03/04/98	45$ S.KULELI SEYH.GD		11,025,000			48,454,382
29/05/98			NAKiT	29/05/98	274$ S.KULELI SYH.GD		70,000,000		21,545,618	
					TOPLAM :		4,274,945,618	4,253,400,000	21,545,618	

Kalan 109.-$